TECHNICAL NOTES

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AERODYNAMIC CHARACTERISTICS OF SEVERAL AIRFOILS OF LOW ASPECT RATIO

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SUMMARY

This paper presents the results of wind-tunnel tests of several airfoils of low aspect ratio. The airfoils included three circular Clark Y airfoils with different amounts of dihedral, two Clark Y airfoils with slots in their after portions, and three flat-plate airfoils. Lift, drag, and pitching-moment characteristics of the circular Clark Y airfoils; lift characteristics of the slotted airfoils with slots open and closed; pitching-moment characteristics of one of the slotted airfoils with slots open and closed; and lift characteristics of the flat-plate airfoils are included.

The results reveal a definite improvement of lift, drag, and pitching-moment characteristics with increase in dihedral of the circular Clark Y wing. Lift characteristics near the stall were found to depend markedly on the shape of the extreme tip but were not greatly affected by slots through the after portion of the airfoils. Changes in plan form of the flat-plate airfoils gave erroneous indications of the effect to be expected from changes in plan form of an airfoil of Clark Y section. The minimum drag characteristics of the circular Clark Y airfoils were found to be substantially the same as for a Clark Y airfoil of conventional aspect ratio.

INTRODUCTION

Wind-tunnel tests of a series of Clark Y airfoils (reference 1) revealed interesting aerodynamic characteristics for airfoils having aspect ratios of the order of 1.27. Experimental airplanes utilizing airfoils of very low aspect ratio have added to the interest in the possibilities of designs embodying such airfoils. The tests reported herein are part of an exploration started to determine the combination of physical features of a low-aspect-ratio wing for optimum aerodynamic characteristics. The exploration has been discontinued because of the pressure of more urgent work.

Included in the present paper are the results of tests of the following airfoils of low aspect ratio: three circular Clark Y airfoils with various amounts of dihedral, two slotted Clark Y airfoils, and three flat-plate airfoils. The tests of the slotted and flat-plate airfoils were in the nature of preliminary work to be used in the preparation of a general program.

APPARATUS AND MODELS

All tests were made on the regular balances installed in the N.A.C.A. 7- by 10-foot atmospheric wind tunnel (reference 2).

The circular Clark Y airfoils with various amounts of dihedral are shown in figure 1. These airfoils were built of laminated mahogany to a precision of 0.01 inch and finished with shellac. The Clark Y airfoil section was preserved to a point as near the tip as practicable, the chord lines being kept parallel to the root chord. The airfoils were 14.14 inches in diameter. The dihedral was varied by changing the curve of the intersection of the chord lines with a plane normal to the chord. The basic curve adopted is given by the relation

$$Z = K(O_{max_r} - O_{max})$$

where Z is the perpendicular distance from a plane including the root chord line to the chord line of the individual section; K is an arbitrary constant; O_{max_r} is the maximum ordinate of the root section; O_{max} is the maximum ordinate of the particular section. Values of K for the airfoils in this investigation were 0, 1, and 2.

The slotted Clark Y airfoils tested are shown in figures 2 and 3. The elliptical airfoil of aspect ratio 1 (fig. 2) is the airfoil without slots for which test results appear in reference 1. The root chord was 14.14 inches and the span 11.11 inches, the construction being similar to that of the circular airfoil with $K = 1$. The airfoil shown in figure 3 was derived from the circular Clark Y airfoil with $K = 1$ by placing the quarter-chord points of the individual sections in a plane perpendicular to the root chord. The root chord and the span for the airfoil tested were each 14.14 inches. The area was that of a circular airfoil 14.14 inches in diameter. The construction of this airfoil was similar to that of the circular airfoils.

The flat-plate airfoils were each 1/16 inch thick, 14.14 inches root chord, and 14.14 inches span. One was circular in plan form; the other was the same in plan form as the airfoil shown in figure 3. This latter airfoil was tested with two different edges at the leading edge so that it served as two airfoils in the test series. These airfoils were made from flat stock steel with the edges smooth and rounded.

TESTS

The lift, drag, and pitching moment were determined for each of the Clark Y airfoils at angles of attack from -5° to 60°. The elliptical airfoil was tested with slots closed, slots open, and with the outer lip of each of the slots on the under surface extended to form an air scoop. The slotted airfoil of aspect ratio 1.27 was tested with slots open and slots closed.

Values of lift and drag were determined for the flat-plate airfoils at angles of attack from 0° to 60°.

All tests were made at an air speed of approximately 80 miles per hour, giving a Reynolds Number of approximately 860,000 based on the root chord.

RESULTS

Results of the tests are presented in standard coefficient form in figures 4 to 11. The effects of varying the dihedral upon the shape of the lift-coefficient curve and upon the value of the maximum lift coefficient appear in figures 4 and 5. Variations of minimum drag coefficient, of the shape of the polar curves, and of pitching-moment coefficients with changes in the dihedral of the airfoil are given in figures 5, 6, and 7, respectively. The pitching-moment coefficients are referred to the quarter-chord point of the root chord. Variations of the curves of lift coefficient against angle of attack with changes in tip shape and plan form, with the addition of slots through the airfoil, and with change of plan form in the case of flat plates, appear in figures 8, 9, and 10, respectively. The pitching-moment characteristics of the slotted airfoil with aspect ratio of 1.27 with slots open and closed are given in figure 11.

The results have not been corrected for tunnel-wall or blocking effects. The probable errors in measurements are as given in reference 2.

DISCUSSION

The circular Clark Y airfoils with various amounts of dihedral were tested as part of a program designed to reveal physical features of low-aspect-ratio airfoils that most markedly affect their aerodynamic characteristics. A circular airfoil with the maximum ordinates of the upper surface in a plane parallel to the root chord of the airfoil had given the best characteristics of the series of low-aspect-ratio airfoils reported in reference 1. The first series of additional tests undertaken involved changing the dihedral angle as indicated in figure 1. The method of variation of the dihedral adopted was chosen because it did not necessitate sharp changes in the shape of the airfoils as seen in a front elevation and because it permitted including the circular airfoil of reference 1 in the regular series.

As will be seen from figure 4, increasing the dihedral moved the angle of attack for zero lift to a lower value and increased the value of the maximum lift coefficient. The trend of the increase in maximum lift coefficient is more clearly shown in figure 5.

The test results indicated the variation of minimum drag coefficient with dihedral shown in figure 5. It is quite possible, however, that slight differences in the accuracy of construction or in the surface finish of the airfoils masked the true effect of the dihedral. It is of especial interest that the airfoils of low aspect ratio gave values of minimum drag coefficient substantially the same as those given by conventional Clark Y airfoils in the 7- by 10-foot tunnel. (See fig. 5.) This result is contradictory to the results presented in reference 1 but confirms tests in the variable-density tunnel with the circular airfoil after it had been refinished. The difference between the present results and those given in reference 1 is thought to have been caused by the difference in finish of the airfoils.

Increasing the dihedral resulted in large reductions in the drag at values of lift coefficient corresponding to climbing and slow cruising speeds. With $K = 2$ the total drag was less than the induced drag computed from the relation $C_{D_i} = \dfrac{{C_L}^2}{\pi \dfrac{b^2}{S}}$ for values of C_L between 0.8 and 1.2. The total drag of this airfoil was approximately 80 percent that of the airfoil with $K = 0$ and 86 percent that of the airfoil with $K = 1$ for values of lift coefficient from 0.3 to 0.7.

Increasing the dihedral resulted in no important effect upon the curves of pitching-moment coefficient referred to the quarter-chord point of the root chord at low values of the lift coefficient but did result in a decrease in the diving moment at high values of the lift coefficient. This effect is favorable in that less control moment would be necessary to obtain a given value of C_L for the airfoil with the greatest dihedral. It is interesting to note that almost the same pitching-moment coefficient was obtained at maximum lift coefficient for each of the airfoils.

Details of tip shape and changes in plan form had large effects upon the maximum lift coefficient obtainable, as shown in figure 8. The only differences between the circular Clark Y airfoil with $K = 1$ reported herein and the original circular Clark Y airfoil reported in reference 1 were in the surface finish and in the shape of the extreme tips. In the case of the original airfoil the tips were slightly rounded; whereas in the new airfoil the tips were carried to a sharp edge. As will be seen from figure 8, the original airfoil apparently had a slightly smaller effective aspect ratio and reached a higher value of maximum lift coefficient. The slotted airfoil of aspect ratio 1.27, when tested with the slots closed, gave lower values of maximum lift coefficient than either of the circular airfoils. The extreme tip shape of this airfoil was the same as that for the circular airfoil with $K = 1$ in the present series of tests.

The preservation of unburbled flow to very high angles of attack, in the case of the airfoils of low aspect ratio, is apparently due to the action of the tip vortices in removing the boundary layer that tends to build up near the trailing edge of the upper surface of the airfoil. A qualitative preliminary exploration of the direction of flow over the upper surface indicated that possibly slots through the airfoils opening upward and outward would further delay the separation of the flow. Two Clark Y airfoils of very low aspect ratio were fitted with slots and tested with slots open and slots closed. As shown by figure 9, there was a slight increase in maximum lift coefficient, but the increase was not sufficient to warrant additional investigations along this line. Fitting air scoops to the lower surface of the airfoil to direct air through the slots had but slight effect.

The diving moment of the slotted airfoil of aspect ratio 1.27 with the slots closed was less than that for the circular airfoil with $K = 1$ throughout the lift-coefficient range. Opening the slots produced increases of the order of 30 percent in diving moment. The slope of the curves with slots open and with slots closed was substantially the same.

Flat plates were tested to determine whether the effect of plan form upon the maximum lift coefficient could be predicted qualitatively for other airfoil sections from such tests. That such a prediction would be reasonably accurate had seemed possible because the tests of reference 1 showed a very great influence of plan form upon the characteristics at very low aspect ratios. The results indicate that an airfoil with the quarter-chord points of the individual sections in a plane perpendicular to the root chord and 25 percent of the root chord back of the leading point of the root section should give higher values of maximum lift coefficient than one of circular plan form. This prediction was not substantiated in the case of the Clark Y airfoil, as may be seen from figure 8.

CONCLUSIONS

1. The minimum drag coefficients of circular Clark Y airfoils do not differ greatly from those for a Clark Y airfoil of conventional aspect ratio.

2. Increasing the dihedral of airfoils of low aspect ratio results in large decreases in drag at values of lift coefficient corresponding to climbing and slow cruising speeds.

3. The value of maximum lift coefficient and of the angle of attack at which it occurs is greatly affected by the shape of the extreme tip of the airfoil.

4. Slots of the type used in this investigation affect but slightly the lift characteristics of low-aspect-ratio airfoils.

5. The nature of the variation of maximum lift coefficient with plan form for airfoils of very low aspect ratio cannot be predicted from tests with flat plates.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 15, 1935.

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1. Zimmerman, C. H.: Characteristics of Clark Y Airfoils of Small Aspect Ratios. T.R. No. 431, N.A.C.A., 1932.

2. Harris, Thomas A.: The 7 by 10 Foot Wind Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 412, N.A.C.A., 1931.

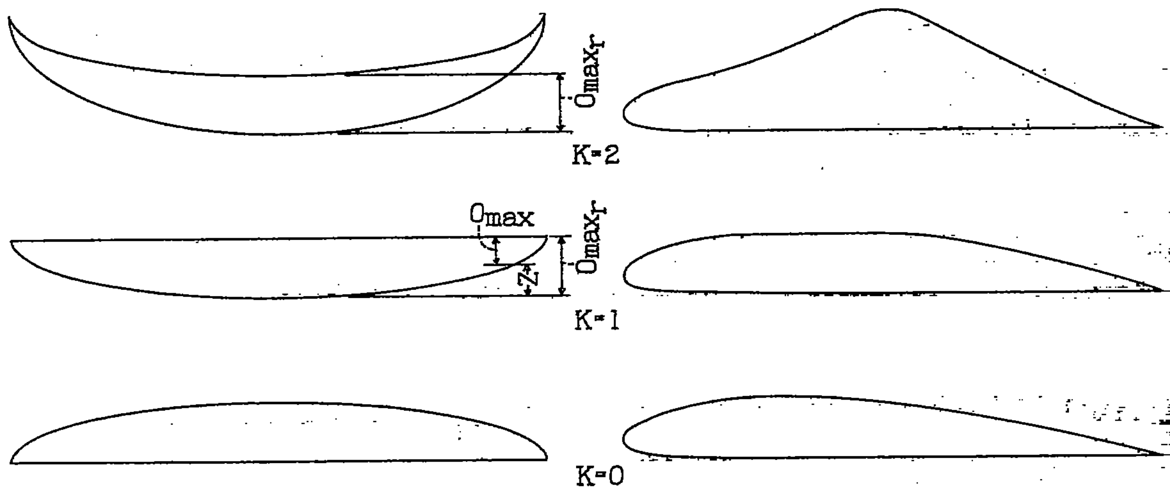

Figure 1.- Circular Clark Y airfoils. $Z = K(O_{max_r} - O_{max})$

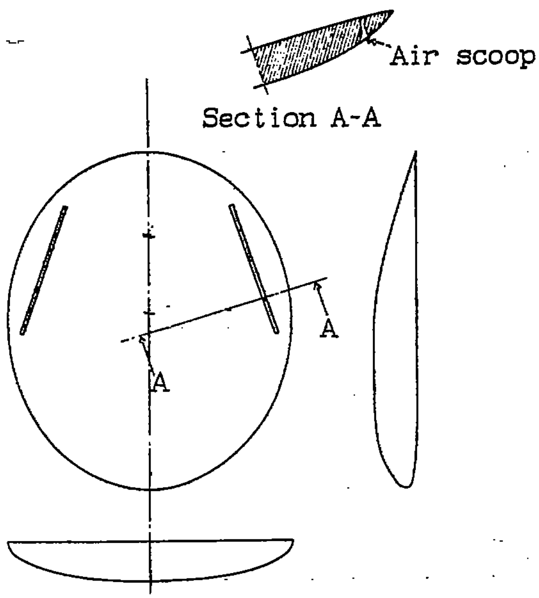

Figure 2.- Slotted low-aspect-ratio airfoil. $b^2/S = 1$
Airfoil section - Clark Y.

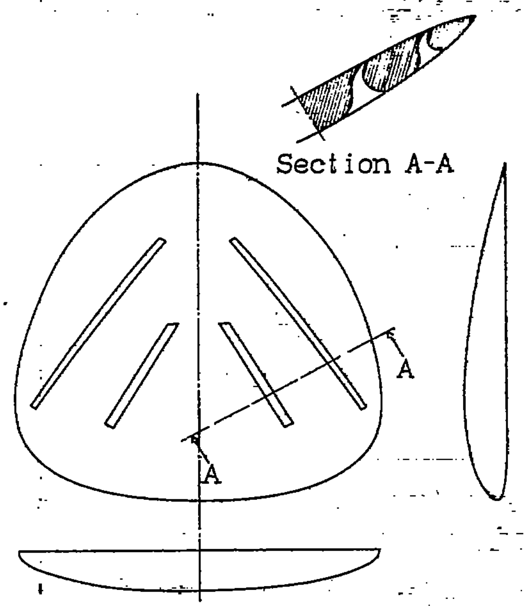

Figure 3.- Slotted low-aspect-ratio airfoil. $b^2/S = 1.27$
Airfoil section - Clark Y.

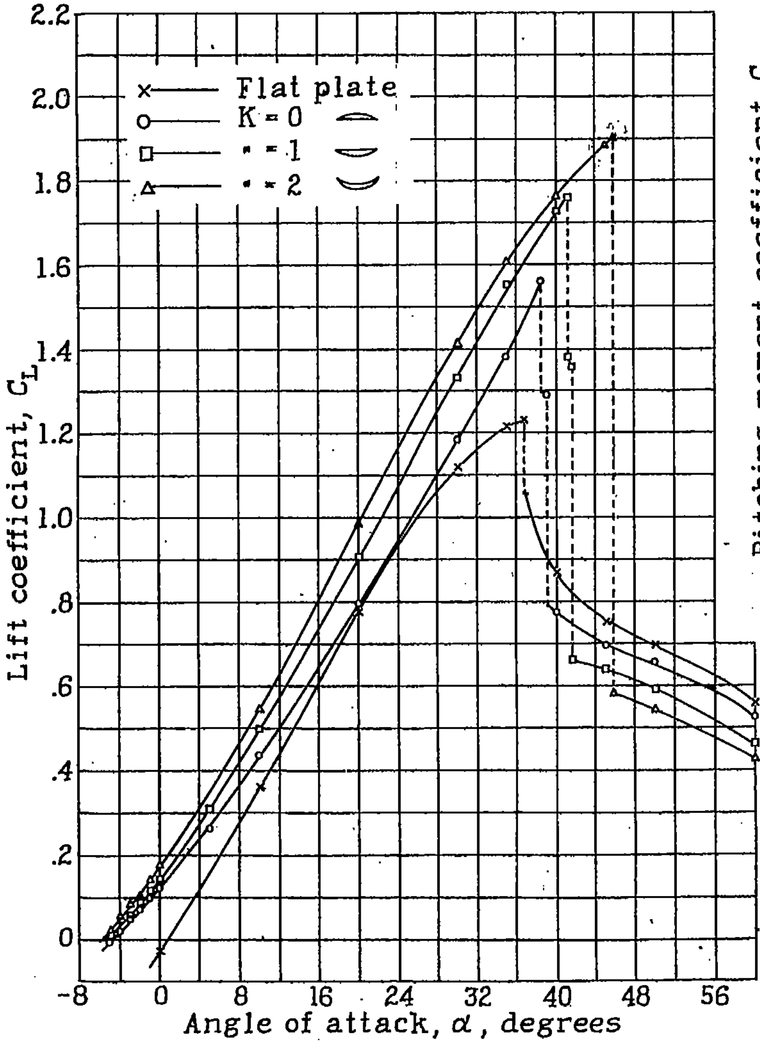

Figure 4.- Effect of dihedral on lift coefficient.
Circular Clark Y airfoils.

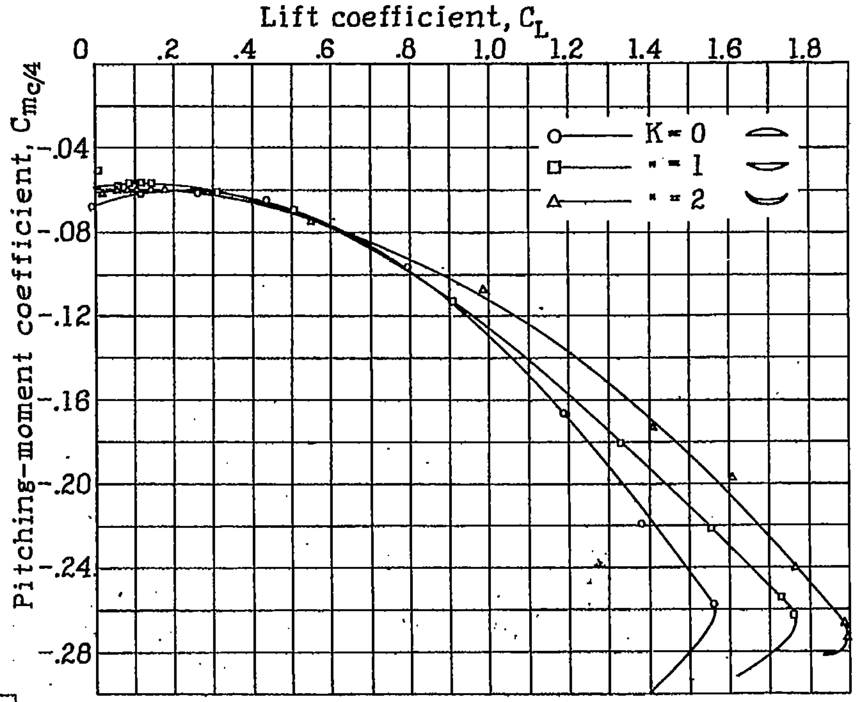

Figure 7.- Effect of dihedral on pitching-moment coefficient.
Circular Clark Y airfoils.

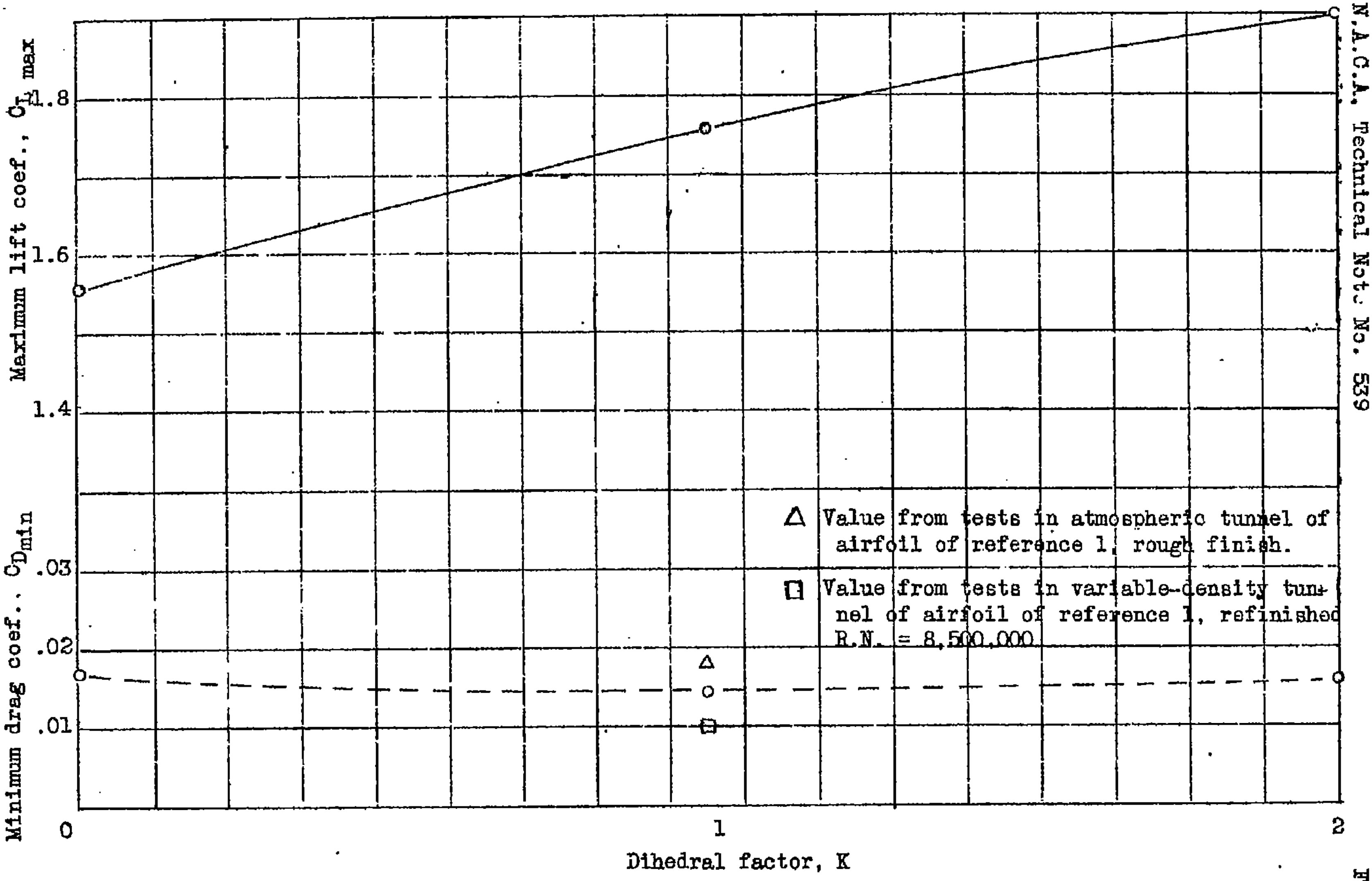

Figure 5.- Effect of dihedral on maximum lift coefficient and minimum drag coefficient. Circular Clark Y airfoils.

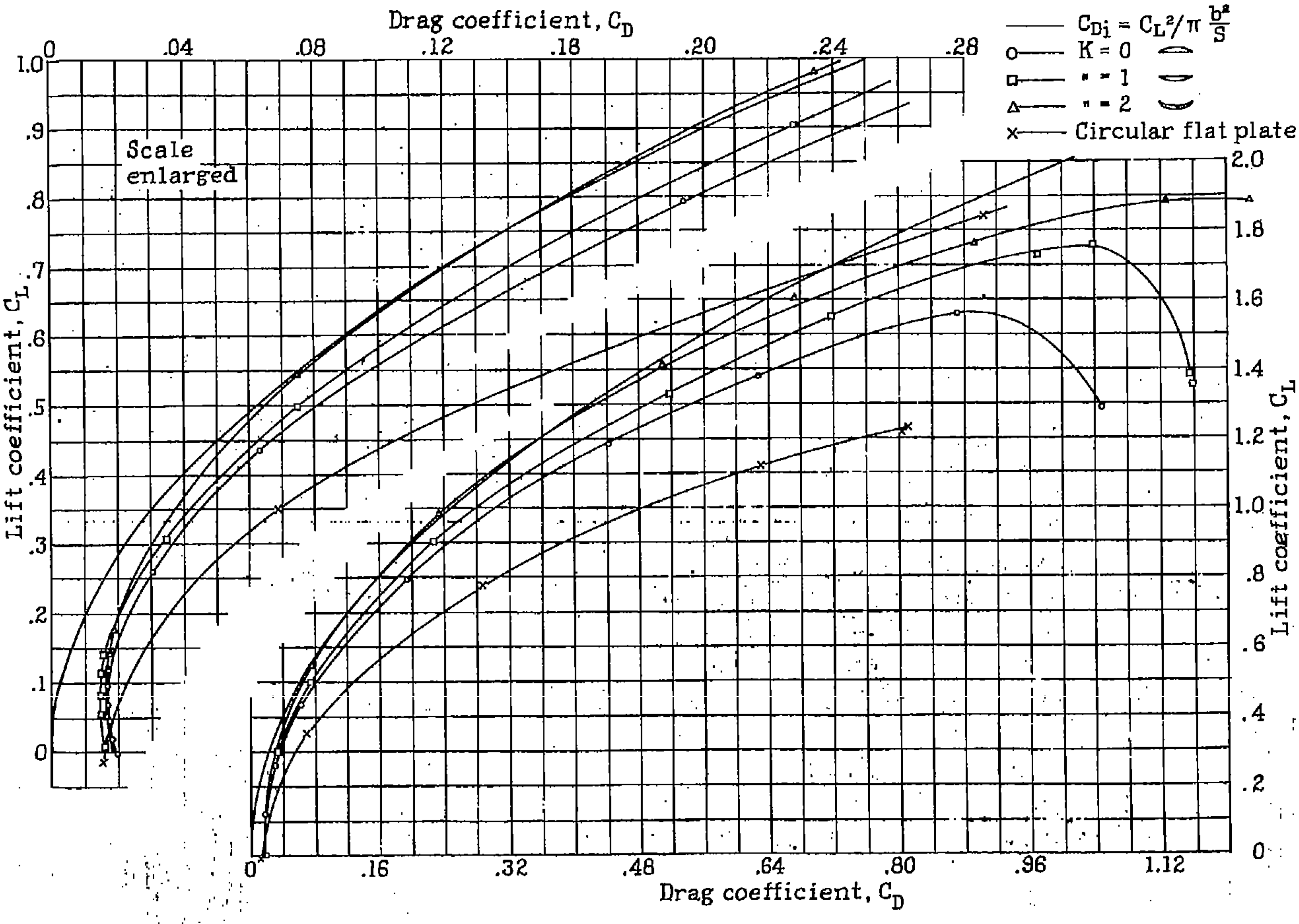

Figure 8. - Effect of dihedral on polar diagram. Circular Clark Y airfoils.

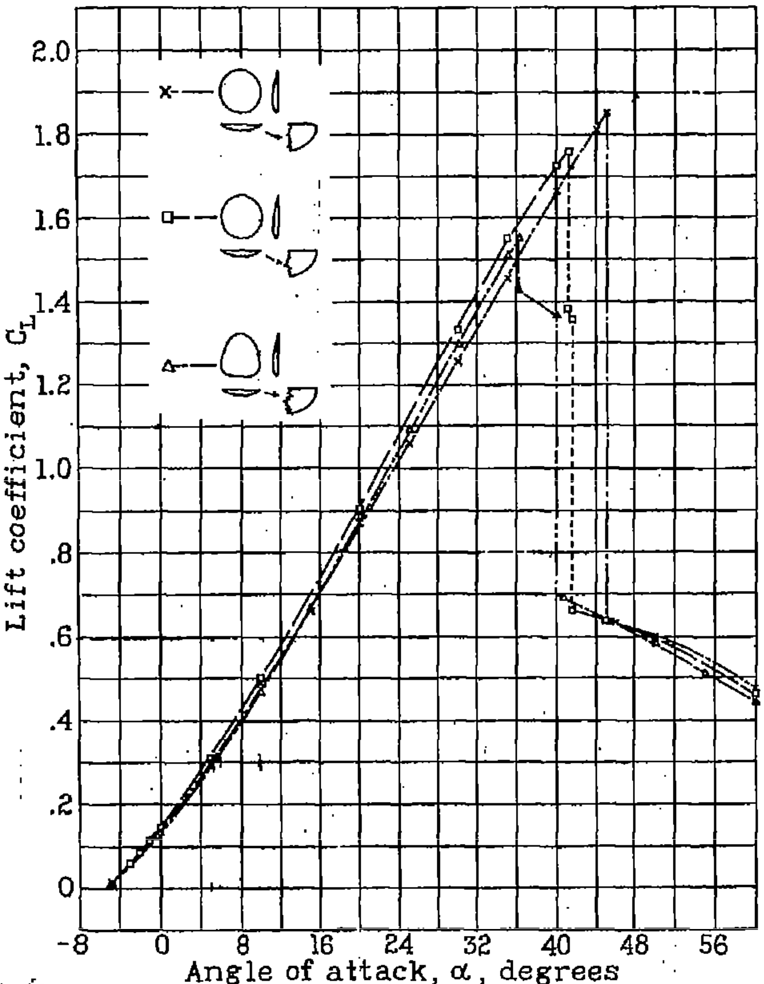

Figure 8.- Effect of tip shape and plan form on lift coefficient. Clark Y airfoils, $b^2/S = 1.27$

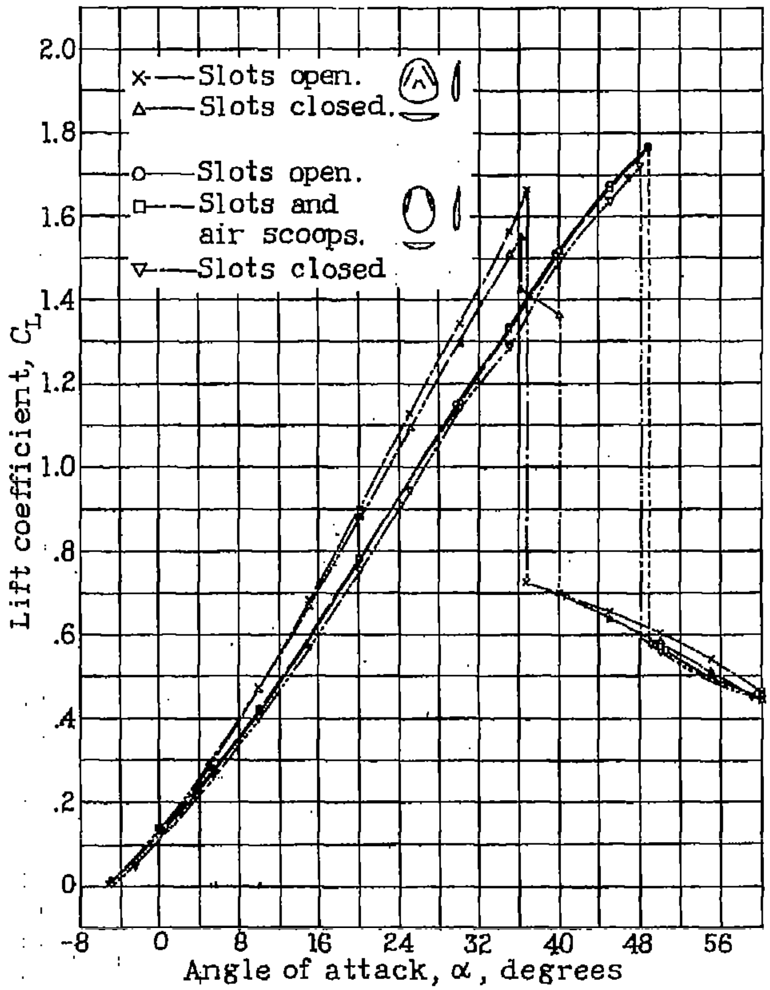

Figure 9.- Effect of slots on lift coefficient. Clark Y airfoils.

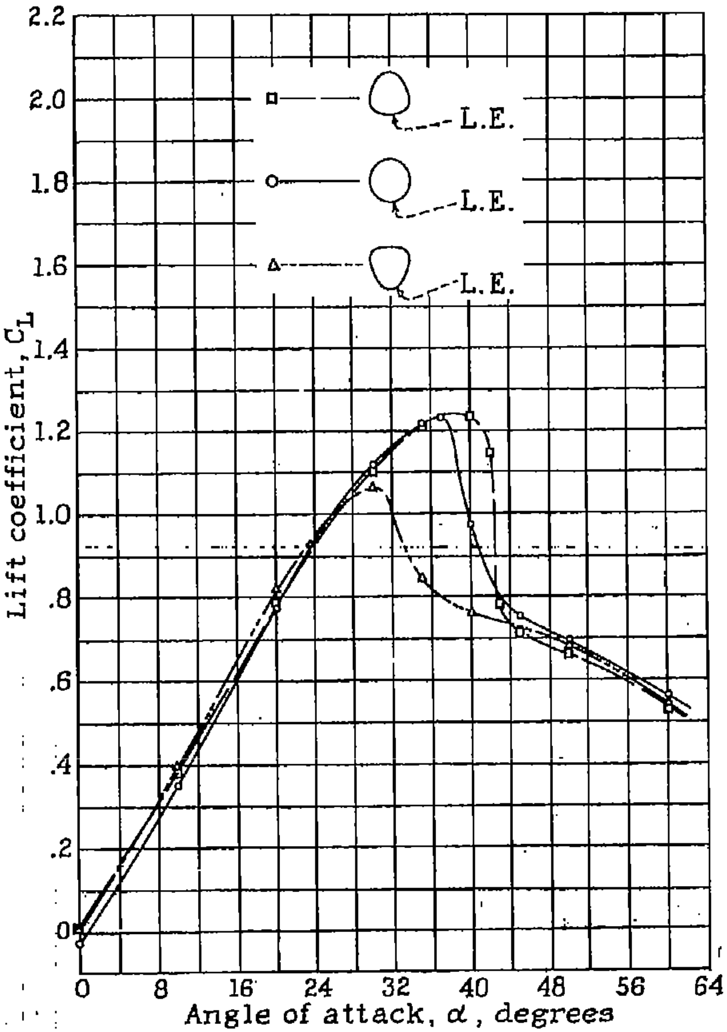

Figure 10.- Effect of plan form on lift coefficient. Flat plate airfoils.

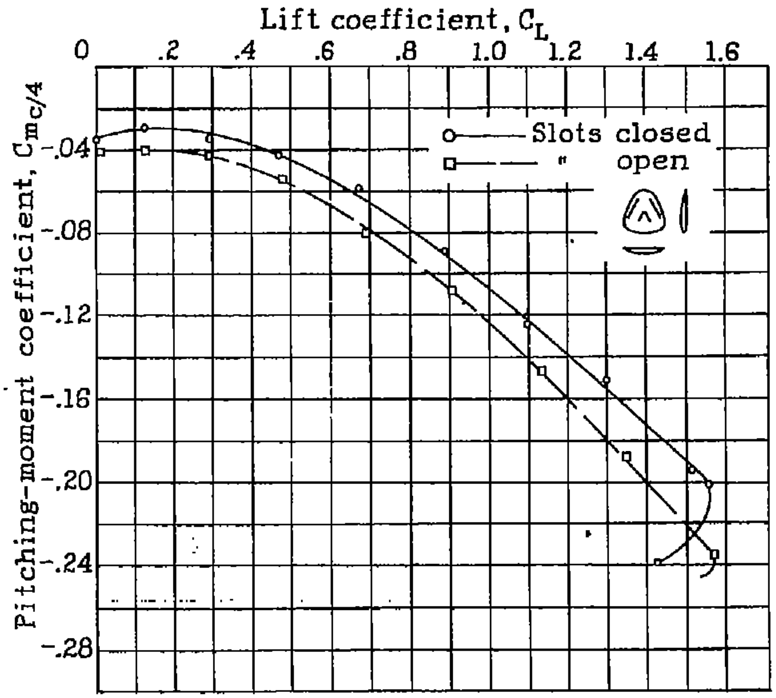

Figure 11.- Effect of slots on pitching-moment coefficient. Clark Y airfoil, $b^2/S = 1.27$.